Changes in electroencephalographic activity associated with learning a novel motor task

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Abstract:

This study was designed to examine changes in EEG activity associated with the learning of a novel task. Right-handed adults ($N = 61$) were randomly assigned to experimental and control groups. Subjects' EEG was recorded at 10 sites. Subjects' performance was assessed using 8-s trials on a mirror star trace. On the acquisition day, the experimental subjects performed 175 trials while the control subjects performed 10 trials, sat quietly for the amount of time needed to perform 155 trials, and then performed 10 more trials. On the retention day, all subjects performed 20 trials. There was a significant Group x Day x Trial interaction that showed that performance improved across trial blocks and across days; however, after the first 10 acquisition trials, the experimental subjects were always significantly better than the control subjects. Analysis of the EEG data showed a significant four-way interaction that showed that following the first 10 acquisition trials, the experimental subjects had more alpha activity than the control subjects. It is concluded that there are consistent EEG changes in the alpha band that are associated with learning a motor task.

Keywords: spectral alpha | motor learning

Article:

Learning is defined as "a set of processes associated with practices or experience leading to relatively permanent changes in the capability for responding" (Schmidt, 1988, p. 346). These changes in the capability for responding are typically measured behaviorally by assessing a person' performance during repeated trials on a task. The relative permanence of the changes is ascertained by having the person perform again at a subsequent testing session (retention period) and then showing that the performance is better than it was during the initial acquisition trials.

It has been suggested that changes in the brain of the organism must take place for learning to result. This hypothesis has been examined using a variety of different techniques. Researchers have used an animal model to show that motor-skill learning can result in structural changes in the brain (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Isaacs, Anderson, Alcantara, Black, & Greenough, 1992). This research has shown that rats that have been taught complex motor skills have experienced significant increases in the numbers of synapses per Purkinje cell as compared to rats in either a control condition or an exercise condition.

Researchers studying learning in humans have begun to use psychophysiological measures such as cerebral blood flow (Grafton et al., 1992), glucose metabolism (Haier et al., 1992), and synchronization of neural firing (Gliner, Mihevic, & Horvath, 1983; Landers et al., 1994) to examine changes in brain activity that occur with learning. Despite the variety of dependent variables used, all of these studies have shown that there are measurable changes in brain activity as a function of learning a novel task. As Haier et al. (1992) concluded, the brains of those who are proficient at a task appear to operate more efficiently than the brains of those who are not proficient at the task. This conclusion is also supported by the results of the Gliner et al. (1983) study and the Landers et al. (1994) study. Since alpha activity is associated with a greater synchronization of neural activity, the results from these two EEG studies provide additional preliminary support for the suggestion that the brain in the skilled performer is operating more efficiently than the brain in the unskilled performer.

However, these past studies have had some major shortcomings, the most critical of which is that neither Grafton et al. (1992) nor Haier et al. (1992), nor Gliner et al. (1983) adequately demonstrated that "learning" had actually occurred. As mentioned above, learning is characterized by "relatively permanent changes in the capability for responding" (Schmidt, 1988, p. 346). Thus, a retention day is needed to ensure that the changes in response are actually relatively permanent–that is, that they are maintained at a subsequent testing period. An additional problem with these studies is that none of them used a control group to insure that changes in brain activity were truly a function of learning and were not an artifact associated with sitting comfortably in a laboratory for a given length of time. Finally, the studies that used EEG measures were limited in that they only assessed EEG activity at a small number of sites on the scalp.

Thus, this study was designed to improve on the past studies by using a retention day to verify that learning had occurred, by using a control group for the purpose of comparison, and by using more EEG sites to assess more regions of activity. The hypothesis was that alpha activity in subjects who learned the task would increase as compared to their own pretest activity and to control subjects. Site and hemisphere variables were also included as exploratory variables to allow for the assessment of alpha activity in a specific rather than a global manner. On the basis of the fact that different regions of the brain are associated with different cognitive functions and considering the findings of earlier research (Grafton et al., 1992; Landers et al., 1994), it was hypothesized that changes in brain activity that occur as a function of learning would occur differentially as a function of the site and hemisphere at which the activity was measured.

Method

Participants

Right-handed male (n = 31) and female subjects *(*n = 30) were recruited from undergraduate courses at a southwestern university. The average age of the participants was 23.84 yrs (SD = 3.81). All participants were asked to read and sign an informed-consent form.

Experimental Design

Subjects were randomly assigned to either the control group or the experimental group. All subjects performed a pretest and a posttest on the acquisition day and the retention day. There were two performance variables: distance (defined as the number of segments traversed on the star) and errors (defined as total errors per 8-s trial divided by distance). A repeated-measures design was conducted for the performance data to test the first hypothesis. Group consisted of two levels (experimental, control), Day consisted of acquisition and retention levels, and Trial consisted of pretest and posttest levels. To test the second hypothesis, EEG alpha power was analyzed within a 2 x 2 x 2 x 5 x 2 (Group x Day x Trial x Site x Hemisphere) repeated-measures design. The levels of Group, Day, and Trial were the same as described above and there were five levels of Site (frontal, temporal, central, parietal, occipital), and two levels of Hemisphere (left and right).

Performance

Performance was measured using an Automatic Mirror Trace (Model 5824, Lafayette Instrument Company, Lafayette, IN). Subjects were required to use their right hands for performance. They were required to hold a metal stylus to trace the outline of a 6-point star. The task is considered a novel task because the subjects are required to trace the star with their only view of the star and their hands being provided through a mirrored reflection. That is, viewing of the star itself was blocked by a metal screen that was set 6 inches above the star and that completely blocked observation of either the star or the subject's hand. An adjustable mirror was set at the back of the star and angled so that the subject could clearly see both the star and his/her hand in the mirror.

Performance was scored as the number of segments traversed on the star and the number of errors made in the 8-s trials. The star was painted in nonmetallic black paint on a metal surface and the apparatus was set up so that any time the subject ventured off the paint and touched the metal surface with the stylus, an electronic counter would automatically score an error. Along the edge of the star, lines marked off quarters of the distance between two adjacent comers so that distances could be scored as total segments traversed plus the fraction between two comers measured to the nearest one-quarter segment.

EEG Assessment

An El Electro Cap made by Electro-Cap International was put on the subjects and adjusted so that the distance from the front of the cap to the bridge of the nose was equivalent to one-tenth of the distance from the protrusion at the base of the scalp to the bridge of the nose. This cap comes in four sizes (46-50 cm, 50-54 cm, 54-58 cm, and 58-62 cm) so that proper electrode placement is ensured (Blom & Anneveldt, 1982). The caps are made of elastic, spandex-type fabric with

recessed, pure tin electrodes sewn in. Electrode gel was applied to the electrodes of interest to create the conductivity needed for taking scalp measures of EEG activity. EEG recordings were taken from the following sites identified by the International 10-20 System (Jasper, 1958): left frontal (F3), right frontal (F4), left central (C3), right central (C4), left temporal (T3), right temporal (T4), left parietal (P3), right parietal (P4), left occipital (O1), and right occipital (O2). Electrical impedance was measured at 30 Hz at the EEG sites and electrode gel was reapplied to any EEG sites that had impedances greater than 5 K ohms.

Additionally, sites at the supra-orbit and external canthus of the right eye and on the nose were lightly abraded and cleaned with isopropyl alcohol. After cleaning of the sites, Beckman 11 mm Ag-AgCl electrodes were applied to these sites. The electrodes surrounding the eye were used to record electrooculographic activity (EOG). This is because eye blinks (EOG) result in movement artifact in the EEG signal and therefore data contaminated with eye blinks were extracted. The electrode on the nose was used as a reference electrode. Electrical impedance was measured at the reference and EOG sites and electrodes were reapplied to any of these sites that had impedances greater than 10K ohms.

The psychophysiological measures were collected on a Grass Model 12 Neurodata Acquisition System physiograph using software developed by Neuroscan, Inc. The high- and low-bandpass filters for the EEG measures were set at 3 and 100 Hz, respectively, and the signals were amplified 50,000 times. The high- and low-bandpass filters for the EOG measures were set at 3 Hz and 100 Hz, respectively, and the signals were amplified 20,000 times. The attenuation of the signal with these filter settings was 50% at 3 Hz and 100Hz, but in the region of interest (from 8 Hz to 12 Hz), attenuation was less than 10%. The sampling rate for all signals was 256 Hz.

Procedure

Subjects read and signed the informed-consent form and then sat quietly while the electrode cap and the three electrodes were attached. Subjects were then randomly assigned to either the control group or the experimental group. Randomization was performed through the use of a random number table with the restriction that equal numbers of each gender appeared in each treatment condition.

Following the initial preparation period, subjects went into a separate testing room, where they were given instructions on the task to be performed. After the apparatus and the nature of the task were explained, subjects were told that they would be performing a number of 8-s trials and that they were to try to get as far as possible on the star with as few errors as possible. The subjects then were asked to listen to the series of tones that would serve as their signal to begin the trials. These tones consisted of a warning signal (low tone), a "go" signal (medium tone), and a "stop" signal (high tone). There was a variable foreperiod of 1 s, 1.5 s, or 2 s, a trial duration of 8 s, and an intertrial interval of 15 s. The subjects were asked to stop moving the stylus immediately when they heard the "stop" signal so that the experimenter could record the distance traversed and the number of errors made on each trial.

On the acquisition day, subjects in the experimental group performed 175 trials with a 3-min break provided after every 60 trials. Following these trials, the experimental subjects were asked

to perform 25 additional "paced" trials at a controlled speed so that they reached the half-way point of the star (distance = 6.0 segments) as close as possible to the end of the 8-s trial. At this point in the acquisition trials, this was easy for the subjects because the mean distance covered after 175 trials was over one and one-half times around the star. Additionally, at this time covering six segments of the star is roughly equivalent to the distance covered by the control subjects during the last 10 acquisition trials *(M* = 5.17 segments).

The control subjects performed 10 trials and then sat quietly and read *The Reader's Digest* for 66 min. This is equivalent to the amount of time needed to perform 155 trials. These subjects then performed 10 more trials.

The incorporation of the paced trials added an important control comparison because during these trials the subjects' speed of movement was controlled, yet the subjects had "learned" the task. It was hypothesized that changes in EEG activity would be found in the experimental subjects as they moved from pretest to posttest and to the retention day and that these changes would be a result of increased efficiency of functioning caused by learning. However, the experimental design was such that the experimental group at the posttest differed from the same group at the pretest in three ways: They had learned to perform better, they had faster hand movement, and they had been in the laboratory for a long period of time. Thus, any differences between the posttest and the pretest could be attributed either to learning, to the increase in speed of hand movement, or to the rest period. Controlling the speed of movement during the paced trials allows for the exclusion of increases in speed of movement as an explanation for any potential changes in EEG in the experimental group. The control group that sits quietly for the same amount of time as the experimental group allows for the exclusion of a rest period as an explanation for changes in EEG activity. Thus any changes from pretest to posttest in the experimental subjects could be attributed to learning to perform better.

All of the subjects returned to the lab 24 to 48 h later for a retention test that consisted of 20 trials. On this day, the preparation period and the instructions were identical to those on the learning day. All subjects then performed 20 trials with the directions to travel as far on the star as possible with the fewest errors.

Data Reduction

Distance data, standardized error data, and EEG data were averaged across each block of 10 trials and were analyzed for the pretest (trials 1-10) and posttest (trials 166-175 for the experimental subjects, trials 11-20 for the control subjects) on the acquisition day, for the pretest (trials 1-10) and posttest (trials 11-20) trials on the retention day, and for 10 of the paced trials (trials 176-185 for the experimental subjects).

The EEG data were collected continuously during performance. The computer that delivered the stimulus also produced TIL pulses in the computer that acquired the EEG data. These pulses corresponded to the warning signal, the "go" signal, and the "stop" signal. The pulses were then used to identify the latencies of the signals so that spectral activity between the "go" and "stop" signals could be analyzed. These TIL pulses were accurate to the interrupt handling latency of the software package (≤ 1 ms). EEG data were examined and epochs containing eye blinks

deleted. This resulted in the omission of three subjects (one control subject and two experimental subjects) from the analyses because they had one or more blocks of trials (i.e., pretest or posttest) that had no clean trials. Following this, spectral analyses of the data were performed on the remaining 58 subjects. The spectral analysis was done using the peak-to-peak method, which provides an amplitude (square root power) spectrum expressed in microvolts. Total power within the alpha band was determined by summing amplitude across the bins between 8 and 12 Hz. The spectral analysis was limited to frequencies in the alpha band (8-12 Hz) because in past work by Gliner et al. (1983) and Landers et al. (1994) changes in EEG activity associated with learning were found primarily in the alpha band.

Data Analysis

The performance data (distance and errors) were analyzed using a repeated-measures multivariate analysis of variance (MANOVA) with Group as a between-subjects factor and Day and Trial as repeated-measures factors. The dependent variables were segments traversed on the star (distance) and errors relative to distance at each of the two days (acquisition and retention) and two trial blocks (pretest and posttest).

The EEG data were analyzed using a MANOVA method for repeated-measures analysis, with Group as a between-subjects factor and Day, Trial, Site, and Hemisphere as within- subjects factors. The dependent variables were alpha power at each of the two days (acquisition, retention) and two trial blocks (pretest, posttest).

When appropriate, the Huynh-Feldt Epsilon was examined to check the sphericity assumption. In cases in which the assumption was not met, multivariate tests of significance were used. To further examine the highest order interactions that reached significance, simple effects were tested to compare means of theoretical interest using pairwise comparisons. For all significant effects, eta-squared (η^2) values were reported as an index of the meaningfulness of significant effects.

Results

Performance Data

The multivariate test for the Group x Day x Trial interaction was significant, Wilks' $\lambda = .26$, $F(2, 55) = 78.50$, $p < .001$, $\eta^2 = .74$. Examination of the univariate F-tests showed that this interaction was significant for distance, $F(1, 56) = 155.18$, $p < .001$, $\eta^2 = .73$, but was not significant for errors, $F(1, 56) = 0.02$, $p > .05$. Therefore, a separate analysis of variance was conducted for distance with Group, Day, and Trial as independent variables. The highest order multivariate test that was significant and for which the univariate test for errors was also significant was the Day x Trial interaction, Wilks' $\lambda = .22$, $F(2, 55) = 99.20$, $p < .001$, $\eta^2 = .78$. Examination of the univariate F-tests showed that this interaction was significant for errors, $F(1, 56) = 10.37$, $p < .002$, $\eta^2 = .16$. Therefore, a separate analysis of variance was conducted for errors with Day and Trial as the independent variables.

Distance. Simple main effects conducted for the Group x Day x Trial interaction revealed that the distance traveled during the pretest on the acquisition day did not differ as a function of group, $t(56) = 1.39$, $p > .05$. However, at the posttest during acquisition and during both retention assessments, the experimental subjects went significantly farther than the control subjects, $t(56) = 6.26\text{-}10.04$, $p < .001$ (see Figure 1).

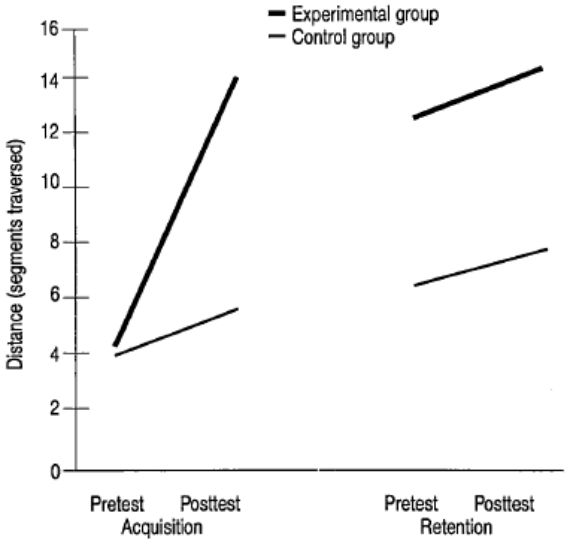

Figure 1. Performance of the two groups as a function of day and trial

Standardized errors. Simple main effects conducted for the Day x Trial interaction showed that the number of errors per distance traveled decreased significantly, $t(57) = 3.19$, $p < .01$, from the pretest *(*$M = .59$, $SD = .90$) to the posttest *(*$M = .29$, $SD = .28$) on the acquisition day and then remained relatively stable across the retention day trials (pretest $M = .27$, $SD = .23$; *posttest* $M = .26$, $SD = .20$). Of primary importance is the fact that the errors did not differ as a function of group. This suggests that the differences in performance between the groups were not caused by a difference in emphasis on speed versus accuracy.

EEG Data

Alpha power. The results showed that the main effect for Hemisphere was not significant; however there were significant main effects for Site, Wilks' $\lambda = .15$, $F(4, 53) = 74.95$, $p < .01$, $\eta^2 = .85$; Day, $F(1, 56) = 8.30$, $p < .01$, $\eta^2 = .13$; and Trial, $F(1, 56) = 8.79$, $p < .01$, $\eta^2 = .14$. Of the 10 two-way interactions, only the Site x Hemisphere interaction was significant, Wilks' $\lambda = .42$, $F(4, 53) = 18.61$, $p < .01$, $\eta^2 = .58$. There were 10 three-way interactions of which only Group x Hemisphere x Day, $F(1,56) = 6.27$, $p < .02$, $\eta^2 = .10$, and Hemisphere x Site x Trial, Wilks' $\lambda = .75$, $F(4, 53) = 4.48$, $p < .01$, $\eta^2 = .25$, were significant. Of the four-way interactions, only Group x Hemisphere x Day x Trial, $F(1, 56) = 4.00$, $p < .05$, $\eta^2 = .07$, and Group x Hemisphere x Day x Site, Wilks' $\lambda = .79$, $F(4, 53) = 3.63$, $p < .02$, $\eta^2 = .21$, were significant. The five-way interaction of Group x Site x Hemisphere x Day x Trial was not significant *(*$p > .05$).

The interaction effect that relates most directly to the findings of past research is the interaction of Group x Hemisphere x Day x Trial (see Figure 2). Independent-samples *t* tests showed that alpha power was not significantly different between the groups at any time in either hemisphere,

ts(56) = 0.68-1.48, *ps* > .05. However, it was found that the increase in alpha activity in the right hemisphere from pretest to posttest on the acquisition day was significant, $t(27) = 2.95$, $p < .01$, but only for the experimental group. This suggests that an increase in alpha activity is associated with the improved performance capabilities that the experimental subjects exhibited at this subsequent testing period.

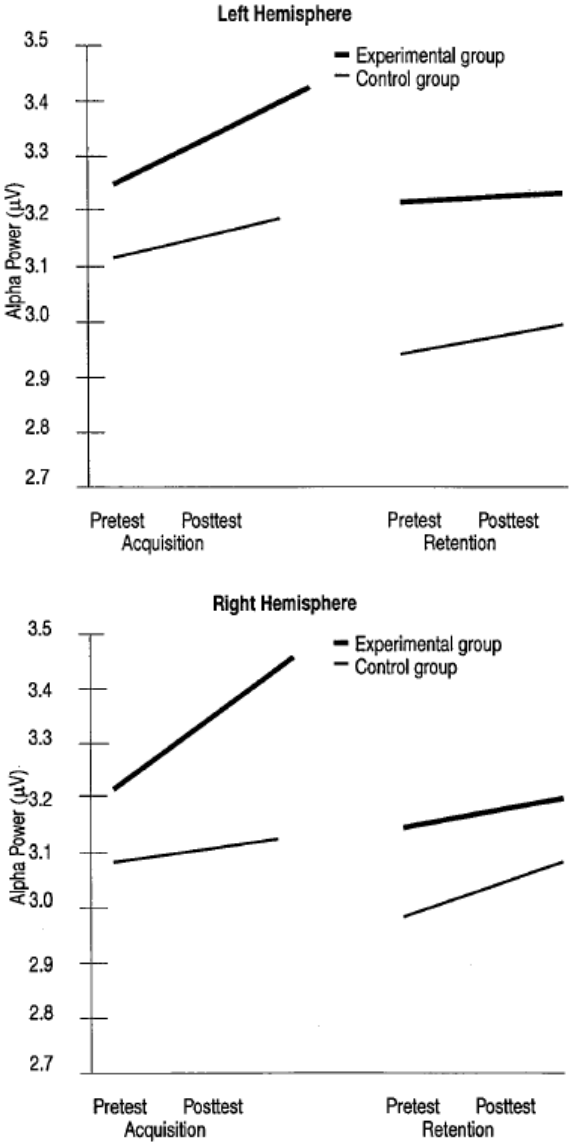

Figure 2. Alpha power of the two groups as a function of hemisphere, day, and trial

Examination of the simple effects involved in the Group x Hemisphere x Site x Day interaction showed that there were no significant differences in alpha activity on the acquisition day or on the retention day at any of the sites as a function of group *(p* > .05). Collapsed across hemisphere, the results showed that alpha power differed significantly among the sites (see Figure 3). The occipital sites had significantly more alpha activity than the parietal sites, $t(57) = 7.06$, $p < .001$, which had significantly more alpha activity than the central sites, $t(57) = 12.57$,

$p < .001$, which had significantly more alpha activity than the temporal and frontal sites, $ts(57) = 13.99\text{-}14.02$, $ps < .001$, which were not significantly different from each other, $p > .05$.

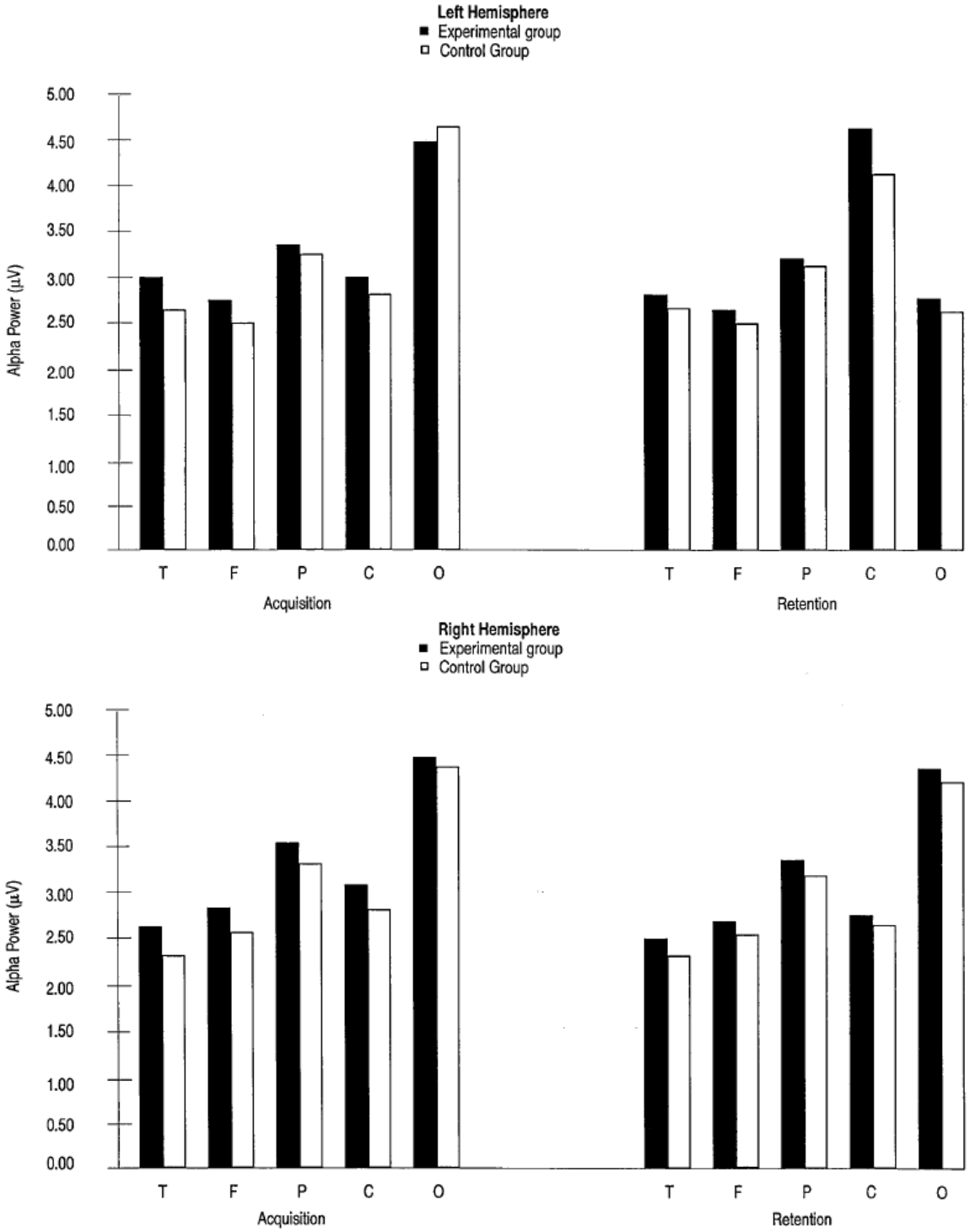

Figure 3. Alpha power of the two groups as a function of hemisphere, day, and site
Note. T = Temporal; F = Frontal; P = Parietal; C = Central; O = Occipital.

Table 1. Alpha power (microvolts) at each site, star performance (distance traveled), and errors (number of times the stylus deviated from the star) as a function of Group, Day, and Trial.

Experimental										
	Acquisition						**Retention**			
	Pretest		**Posttest**		**Paced**		**Pretest**		**Posttest**	
Site	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
L. frontal	2.61	0.68	2.80	0.84	2.74	0.80	2.58	0.58	2.61	0.60
R. frontal	2.74	0.66	2.94	0.85	2.91	0.77	2.65	0.58	2.67	0.59
L. temporal	2.87	0.95	3.15	1.25	3.04	1.15	2.83	0.80	2.84	0.83
R. temporal	2.59	0.79	2.77	0.89	2.77	0.96	2.51	0.71	2.50	0.72
L. central	2.85	0.65	3.02	0.87	2.97	0.87	2.82	0.60	2.83	0.60
R. central	2.97	0.66	3.23	0.90	3.35	1.00	2.85	0.60	2.89	0.63
L. parietal	3.34	0.76	3.51	0.95	3.39	0.95	3.28	0.66	3.29	0.68
R. parietal	3.42	0.77	3.71	0.96	3.63	1.00	3.34	0.64	3.39	0.67
L. occipital	4.42	1.50	4.48	1.50	4.14	1.28	4.66	1.62	4.71	1.79
R. occipital	4.36	1.64	4.61	1.51	4.25	1.41	4.41	1.50	4.50	1.57
Performance	4.35	2.10	14.20	4.22	5.72	1.33	12.80	3.42	14.19	4.75
Error	1.70	1.54	3.52	2.47	0.22	0.50	2.63	2.29	3.05	2.19
Error/Perf	0.51	0.70	0.24	0.16	0.07	0.19	0.20	0.15	0.23	0.17
Control										
	Acquisition						**Retention**			
	Pretest		**Posttest**				**Pretest**		**Posttest**	
Site	**M**	**SD**	**M**	**SD**			**M**	**SD**	**M**	**SD**
L. frontal	2.54	0.55	2.50	0.51			2.49	0.51	2.45	0.44
R. frontal	2.63	0.65	2.57	0.56			2.56	0.51	2.60	0.51
L. temporal	2.67	0.73	2.66	0.84			2.57	0.70	2.59	0.70
R. temporal	2.45	0.89	2.32	0.76			2.28	0.64	2.31	0.62
L. central	2.84	0.68	2.74	0.56			2.70	0.56	2.65	0.49
R. central	2.95	0.95	2.81	0.66			2.78	0.66	2.85	0.61
L. parietal	3.43	1.05	3.28	0.77			3.15	0.69	3.18	0.66
R. parietal	3.47	1.11	3.34	0.85			3.19	0.76	3.29	0.76
L. occipital	4.58	1.84	4.70	2.28			4.04	1.56	4.15	1.39
R. occipital	4.47	1.88	4.55	2.23			4.14	1.68	4.28	1.71
Performance	3.72	1.69	5.17	2.05			3.88	2.05	7.81	2.47
Error	1.76	1.38	1.56	1.29			2.02	1.53	2.03	1.42
Error/Perf	0.68	1.05	0.33	0.35			0.32	0.27	0.27	0.23

Note. L. = Left; R. = Right

Paced trials. After the pretest trials, the experimental subjects always traveled significantly farther on the star than the control subjects *(*$p < .001$). However, when the experimental subjects were asked to pace themselves so as to only complete one-half of the star in the trial period, an independent-samples *t* test showed that the average distance *(*$M = 5.72$ segments, $SD = 1.33$) was not significantly different—$t(56) = 1.20$, $p > .05$—from that of the control subjects *(*$M = 5.17$ segments, $SD = 2.05$).

To examine the question of whether changes in alpha activity were a function of actual learning or merely of speed of movement, the alpha activity during the paced trials was substituted for the alpha activity at the posttest on the acquisition day for the experimental subjects and the previously described MANOVA was conducted. When this was done, the four-way interaction of Group x Hemisphere x Day x Trial was still significant, $F(1, 55) = 9.88$, $p < .01$, $\eta^2 = .15$. Examination of the means showed that the nature of this interaction was not changed by the incorporation of alpha activity during paced trials instead of alpha activity during speeded trials. That is, following the pretest on the acquisition day, alpha activity in both hemispheres was greater for the experimental subjects than for the control subjects regardless of the speed of movement (inferred from the distance traveled on the star in 8 s).

Discussion

The study was designed to examine the relationship between EEG activity and learning. Results showed that relatively permanent changes in performance did occur. This is evidenced by the fact that the experimental subjects performed significantly better than the control subjects during the posttest acquisition trials and that this better performance was maintained throughout the retention period.

Associated with these improvements in performance were: (a) significant increases in EEG alpha in the experimental group from the pretest trials to the posttest trials on the acquisition day, and (b) higher alpha activity in the experimental subjects than in the control subjects at both trials on the retention day. From these results, it is concluded that increases in alpha are associated with improvements in performance.

The incorporation of the paced trials for the experimental subjects and the fact that this did not change the nature of the interaction involving test days and sessions is important because this suggests that the differences in alpha activity which were found were not merely a function of increased speed of movement, but were actually a function of the process of learning. According to Andreassi (1980), increases in alpha activity are indicative of increases in the synchronization of neural activity. Therefore, the results of this study support the suggestion by Haier et al. (1992) that the brains of subjects who are skilled at a task may function more efficiently than the brains of those who are novices. However, there are many other possible interpretations of these findings that must be considered. For example, it is possible that the changes in alpha activity actually reflect the response of the experimental subjects to their ability to perform well. That is, it may reflect an attenuation of the stress response in subjects who could successfully complete the task (experimental subjects) as compared to an elevation of the stress response in subjects who could not successfully complete the task (control subjects). There are myriad other explanations for this phenomenon and future study is needed to determine whether the increase

in alpha activity found in this study is a concomitant effect of task improvement, is a cause of task improvement, is a result of task improvement, is not related at all to task improvement, or is related to another variable that is itself related to task improvement.

The effect of learning on alpha activity in the two hemispheres was also examined in this study. An increase in alpha activity was found in both hemispheres from the pretest to subsequent testing sessions. However, the largest and only significant change in alpha activity occurred in the right hemisphere from pretest to posttest on the acquisition day for the experimental group. Despite the different units of measurement for alpha and the slightly different designs of other studies, these findings are similar to those of Gliner et al. (1983). These researchers showed that after performing 15 trials of the mirror-star trace there was a significant increase in mean frequency in alpha band width; however, this increase was not mediated by hemisphere. The mediating effect of hemisphere on the alpha changes, which were found in this study, support the findings of Grafton et al. (1992) and Landers et al. (1994), who showed that changes occurred in left hemisphere brain activity as a function of learning. Therefore, it appears that changes in alpha activity that occur with learning may occur differentially in the two hemispheres; however, it is important to remember that this interaction only accounted for 7% of the variance and that therefore verification of these explanations will rely on findings from future studies.

The differences in alpha activity at the individual EEG sites are difficult to interpret in relation to past studies on EEG changes that occur with learning. The difficulty arises because Landers et al. (1994) only measured EEG at temporal sites, whereas Gliner et al. (1983) only used occipital and parietal sites. Neither of these past studies looked at differential changes in activity levels across the brain that occur with learning. In this study, significant differences in EEG activity at the sites were not found to be a function of the treatment condition. Therefore, definite conclusions cannot be drawn regarding the differential changes in EEG activity across the sites. However, it is important to remember that EEG alpha activity was greater in the experimental group than in the control group at 9 of 10 sites on both days and that EEG alpha activity increased significantly for the experimental group from pretest to posttest on the acquisition day. Therefore, it is concluded that increases in alpha activity are associated with the learning of a novel motor task.

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Author Notes

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